

REPORT DOCUMENTATION PAGE

*Form Approved
OMB No. 0704-0188*

Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing this collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden to Department of Defense, Washington Headquarters Services, Directorate for Information Operations and Reports (0704-0188), 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to any penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number. **PLEASE DO NOT RETURN YOUR FORM TO THE ABOVE ADDRESS.**

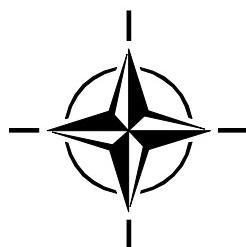
1. REPORT DATE (DD-MM-YYYY)			2. REPORT TYPE			3. DATES COVERED (From - To)		
4. TITLE AND SUBTITLE			5a. CONTRACT NUMBER					
			5b. GRANT NUMBER					
			5c. PROGRAM ELEMENT NUMBER					
6. AUTHOR(S)			5d. PROJECT NUMBER					
			5e. TASK NUMBER					
			5f. WORK UNIT NUMBER					
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)			8. PERFORMING ORGANIZATION REPORT NUMBER					
9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES)			10. SPONSOR/MONITOR'S ACRONYM(S)					
			11. SPONSOR/MONITOR'S REPORT NUMBER(S)					
12. DISTRIBUTION / AVAILABILITY STATEMENT								
13. SUPPLEMENTARY NOTES								
14. ABSTRACT								
15. SUBJECT TERMS								
16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON			
a. REPORT U					b. ABSTRACT U		c. THIS PAGE U	
SAR								



Low-Cost Navigation Sensors and Integration Technology

(Les capteurs de navigation à bas coût et la technologie d'intégration)

The material in this publication was assembled to support a Lecture Series under the sponsorship of the Sensors and Electronics Technology Panel (SET) presented on 27-28 October 2008 in Madrid, Spain, on 30-31 October 2008 in Delft, The Netherlands, on 3-4 November 2008 in Farnborough, United Kingdom, on 19-20 March 2009 in Rome, Italy, on 23-24 March 2009 in Munich, Germany and on 26-27 March 2009 Warsaw, Poland.



Published March 2009

The Research and Technology Organisation (RTO) of NATO

RTO is the single focus in NATO for Defence Research and Technology activities. Its mission is to conduct and promote co-operative research and information exchange. The objective is to support the development and effective use of national defence research and technology and to meet the military needs of the Alliance, to maintain a technological lead, and to provide advice to NATO and national decision makers. The RTO performs its mission with the support of an extensive network of national experts. It also ensures effective co-ordination with other NATO bodies involved in R&T activities.

RTO reports both to the Military Committee of NATO and to the Conference of National Armament Directors. It comprises a Research and Technology Board (RTB) as the highest level of national representation and the Research and Technology Agency (RTA), a dedicated staff with its headquarters in Neuilly, near Paris, France. In order to facilitate contacts with the military users and other NATO activities, a small part of the RTA staff is located in NATO Headquarters in Brussels. The Brussels staff also co-ordinates RTO's co-operation with nations in Middle and Eastern Europe, to which RTO attaches particular importance especially as working together in the field of research is one of the more promising areas of co-operation.

The total spectrum of R&T activities is covered by the following 7 bodies:

- AVT Applied Vehicle Technology Panel
- HFM Human Factors and Medicine Panel
- IST Information Systems Technology Panel
- NMSG NATO Modelling and Simulation Group
- SAS System Analysis and Studies Panel
- SCI Systems Concepts and Integration Panel
- SET Sensors and Electronics Technology Panel

These bodies are made up of national representatives as well as generally recognised 'world class' scientists. They also provide a communication link to military users and other NATO bodies. RTO's scientific and technological work is carried out by Technical Teams, created for specific activities and with a specific duration. Such Technical Teams can organise workshops, symposia, field trials, lecture series and training courses. An important function of these Technical Teams is to ensure the continuity of the expert networks.

RTO builds upon earlier co-operation in defence research and technology as set-up under the Advisory Group for Aerospace Research and Development (AGARD) and the Defence Research Group (DRG). AGARD and the DRG share common roots in that they were both established at the initiative of Dr Theodore von Kármán, a leading aerospace scientist, who early on recognised the importance of scientific support for the Allied Armed Forces. RTO is capitalising on these common roots in order to provide the Alliance and the NATO nations with a strong scientific and technological basis that will guarantee a solid base for the future.

The content of this publication has been reproduced directly from material supplied by RTO or the authors.

Published March 2009

Copyright © RTO/NATO 2009
All Rights Reserved

ISBN 978-92-837-0075-3

Single copies of this publication or of a part of it may be made for individual use only. The approval of the RTA Information Management Systems Branch is required for more than one copy to be made or an extract included in another publication.

Low-Cost Navigation Sensors and Integration Technology

(RTO-EN-SET-116(2009))

Executive Summary

The objective of this two-day Lecture Series was to present the current state-of-the-art in navigation sensors and system integration technology through the improved use of advanced, low-cost navigation sensor technologies. Lecturers presented material that provided an understanding of the issues faced by today's system designers. Through this Lecture Series, the technical community was updated on sensors and current integration techniques as practiced by leading experts in the field. The Lecture Series included tutorial information to bring the audience up-to-date with current practices, as well as, information on sensors and applications. Technology trends were described for navigating in difficult urban, indoor, and underground environments where typical GPS receivers do not function.

The first day began with an overview paper that focuses on accuracy and other technology trends for inertial sensors, Global Positioning Systems (GPS), and integrated Inertial Navigation System (INS/GPS) systems that will lead to better than 1-m accuracy navigation systems of the future. The paper provides the rationale for the remaining papers. The second paper starts with a brief overview of inertial sensing and the technology trends underway. Discussions are presented on gyro and accelerometer technology development, with specific emphasis on designs and performance of Ring Laser Gyros, Fiber Optic Gyros, and MEMS sensors. The third paper provides an overview of the major computational elements associated with strapdown inertial systems. The fourth paper provides an overview of assorted analysis techniques associated with strapdown inertial systems and computational elements. The fifth paper focuses on INS/GPS integration architectures including "loosely coupled", "tightly coupled", and "deeply integrated" configurations. The advantages and disadvantages of each level of integration are discussed. In the sixth and final paper of the first day, the three major INS/GPS systems architectures discussed in the previous paper had their performance compared for various mission scenarios.

The second day of the Lecture Series focused on sensors and applications. The first paper discusses MEMS. The specific advantage of MEMS in ruggedness and size is demonstrated with reference to specific applications, such as guided munitions. The second paper focuses on the latest technology trends for navigating in difficult urban, indoor, and underground environments where typical GPS receivers do not function. Alternative navigation technologies based on electro-optical techniques were described. These included optically aided and ladar-aided INS. The last paper focuses on additional novel technology trends for navigating in difficult environments. These novel technologies are based on RF Signals of Opportunity and biologically inspired navigation.

Les capteurs de navigation à bas coût et la technologie d'intégration

(RTO-EN-SET-116(2009))

Synthèse

L'objectif de cette Suite de Conférences de deux jours était de présenter l'état de l'art en matière de capteurs de navigation et de technologie d'intégration des systèmes avec une meilleure utilisation de technologies évoluées et à bas coût de capteurs de navigation. Les conférenciers ont présenté le matériel qui permettait de comprendre les problèmes auxquels sont confrontés les concepteurs actuels des systèmes. A travers cette suite de conférences, la communauté technique a reçu une mise à jour sur les capteurs et les techniques d'intégration actuelles telles qu'elles sont pratiquées par les meilleurs experts du domaine. La Suite de Conférences comprenait des travaux dirigés afin que les auditeurs soient informés sur les pratiques actuelles mais aussi sur les capteurs et leurs applications. Des orientations technologiques ont été décrites pour la navigation souterraine, pratiquée en intérieur ou en milieu urbain difficile, là où les récepteurs GPS classiques ne fonctionnent pas.

Le premier jour a commencé par une vue d'ensemble mettant l'accent sur la précision et les autres orientations technologiques pour les capteurs inertiels, le *Global Positioning Systems* (GPS) et les Systèmes de Navigation Inertiels intégrés (INS/GPS) qui porteront la précision des systèmes de navigation futurs à moins d'un mètre. Le document donnait son point de vue sur les documents suivants. Le second document commençait par une vue d'ensemble courte sur le sensing inertiel et les orientations technologiques en cours. Les débats sur le développement technologique des accéléromètres et des gyroscopes ont été présentés, l'accent étant particulièrement mis sur la conception et les performances des Gyroscopes à laser Périphériques, des gyroscopes à Fibres Optiques et des capteurs MEMS. Le troisième document fournit une vue d'ensemble des principaux éléments de calcul associés aux centrales inertielles liées. Le quatrième document fournit une vue d'ensemble sur un choix de techniques d'analyse associées aux systèmes inertiels liés et aux éléments de calcul. Le cinquième document s'intéresse aux architectures d'intégration INS/GPS comprenant les configurations « légèrement couplé », « fortement couplé » et « profondément intégré ». Les avantages et les désavantages de chaque niveau d'intégration sont examinés. Dans le sixième et dernier document du premier jour, les trois principales architectures des systèmes INS/GPS examinées dans le document précédent ont été comparées suivant leurs performances dans divers scénarios de missions.

Le second jour de cette Suite de Conférences a été consacré aux capteurs et à leurs applications. Le premier document a traité des MEMS. Les avantages spécifiques des MEMS du point de vue de la robustesse et de la taille ont été démontrés en faisant référence à des applications spécifiques comme les munitions guidées. Le second document s'est intéressé aux dernières orientations technologiques sur la navigation souterraine, pratiquée en intérieur ou en milieu urbain difficile, là où les récepteurs GPS classiques ne fonctionnent pas. Des technologies de navigations alternatives basées sur les techniques électro-optiques ont été examinées. Celles-ci comprennent les INS assistés optiquement et assistés lidar. Le dernier document est consacré aux orientations technologiques nouvelles sur la navigation en environnement difficile. Ces technologies nouvelles sont basées sur les Signaux d'opportunité RF et sur la navigation inspirée de la biologie.

List of Authors

Lecture Series Director

Dr. George T. SCHMIDT

10 Goffe Rd
Lexington, MA 02421
United States

gtschmidt@alum.mit.edu

Authors

Dr. Neil M. BARBOUR

Distinguished Member of the Technical Staff
The Charles Stark Draper Laboratory, Inc.
555 Technology Square, MS 68
Cambridge, MA 02139-3563
United States

nbarbour@draper.com

Dr. Mikel M. MILLER

Technical Director, Advanced Guidance Division
Munitions Directorate, Air Force Research
Laboratory
AFRL/MNG
101 W. Eglin Blvd. Suite 267
Eglin AFB, FL 32542-6810
United States

mikel.miller@eglin.af.mil

Mr. Benjamin BRAUN

Technische Universität München
Boltzmannstraße 15
D-85748 Garching
Germany

benjamin.braun@tum.de

Mr. Paul G. SAVAGE

President
Strapdown Associates, Inc.
4727 South Lake Sarah Drive
Maple Plain, Minnesota 55359
United States

pgs@strapdownassociates.com

RTA/OCD POC

Mr. Nicolas Vandenabeele

RTA Paris
Tel: +33 (0) 1 55 61 22 14
FAX: + 33 (0) 1 55 61 96 10

E-mail : vandenabeele@rta.nato.int

